“MASSETER THICKNESS BY ULTRASONOGRAPHY, FACIAL MORPHOLOGY, FACIAL FORM AND MAXILLARY ARCH WIDTH IN FEMALES”

The Dissertation submitted to
The Tamilnadu Dr. M.G.R. Medical University
in partial fulfillment for degree of
MASTER OF DENTAL SURGERY,
BRANCH-V, ORTHODONTICS
FEBRUARY-2006

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ACKNOWLEDGEMENTS

I express my gratitude to **Dr. L. Muthusamy, M.D.S,** Head of the Department, Department of Orthodontics, Tamilnadu Government Dental College and Hospitals, Chennai, for the precious guidance, support and the constant encouragement throughout the entire duration of this study.

I express my sincere thanks to **Dr. W. S. Manjula, M.D.S,** Additional Professor, Department of Orthodontics, Tamilnadu Government Dental College and Hospitals, Chennai, for her important suggestions, words of constructive criticism and valuable guidance in making this work possible.

I wish to extend my thanks to **Dr. C. Karunanidhi, M.D.S,** Additional Professor, Department of Orthodontics, Tamilnadu Government Dental College and Hospitals, Chennai, for his support during the study.

I thank **Dr. C. Kumaravel, M.D.S,** Principal, Tamilnadu Government Dental College and Hospitals, Chennai, for granting me permission to use the facilities available in the college.

I am bound to acknowledge the constant support and motivation extended by my Assistant Professors, **Dr.G.Vimala,M.D.S, Dr.S.Premkumar,M.D.S, and Dr.J. Nagalakshmi, M.D.S.** throughout the study.

I thank **Dr. S. Swaminathan**, Director, Barnard Institute of Radiology, Govt General Hospital, for allowing me to undertake the study from the institute. I also thank **Dr.Tixon Thomas**, Barnard Institute of Radiology, for undertaking the tedious process of evaluation of muscle thickness by ultrasound.

I express my sincere thanks to **Dr. Govinda Reddy**, Associate Professor, Department of Physical Anthropology, Madras University for training me in Anthropometry.

I express my gratitude to **Mr. G. Ravanan**, Reader, Statistics Department, Presidency College, for doing the statistical analyses.

Last but not the least, I wish to extend my sincere thanks to the dental students who participated in the study and my batch mates and juniors who helped me with data collection.

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INTRODUCTION

Certain parameters of masticatory muscle function have been shown to correlate with facial morphology, including electromyographic activity and occlusal force. With the advent of modern imaging techniques, it became possible to measure the size of masticatory muscles *in vivo*. Computed tomography, Magnetic resonance imaging, and Ultrasonography have been used to measure various muscle dimensions like volume, cross sectional area, thickness, width, length and surface area. Out of the various imaging techniques, Ultrasonography has the distinction of being accurate, convenient, easy, and inexpensive to apply. There are no reports of adverse biological effects with diagnostic ultrasound. High degree of reliability and accuracy has been shown in the estimation of masseter muscle thickness with all the above mentioned imaging techniques including Ultrasonography.

Craniofacial morphology and jaw muscle cross sectional area are related, cross sectional area being an indication of the maximal force a muscle is capable of producing. Thinner masseter muscle is found in long face subjects with obtuse gonial angle. A positive association between thickness of masticatory muscles and craniofacial widths has been reported, i.e. subjects with thicker masticatory muscles have broader faces with broader dental arches.

Linear, angular and proportional measurements were taken from the lateral cephalograms of females, 21-23 years of age in this study. Using a spreading caliper, dimensions of the face and cranium were obtained by anthropometry and anthropological indices were calculated. Maxillary inter-molar widths were measured from stone casts. Correlations were sought between these variables and masseter thickness in relaxed and contracted states obtained through Ultrasonography.

No study is published in the literature so far which relates the masseter muscle thickness to lateral cephalometric findings, transverse anthropometric readings and maxillary inter-molar width. The purpose of this study is to evaluate the role of masseter muscle in the transverse and vertical dento-facial growth.

AIMS AND OBJECTIVES

The aim of the present study is to investigate the relationship between thickness of masseter muscle and facial morphology variables. Put in detail, the objective is to :

1. Quantitate the normal range of masseter thickness in adult females in relaxed and contracted states.

2. Relate the variation in the thickness of the masseter muscle in relaxed and contracted states to the variations in the facial morphology as seen on lateral cephalograms.

3. Relate the variation in thickness of masseter muscle in relaxed and contracted states to cranial and facial dimensions evaluated through anthropometry.

4. Relate the variation of thickness of masseter muscle in relaxed and contracted states to the maxillary inter-molar width.

REVIEW OF LITERATURE

J Wolff (1870)[116] pointed out that the trebecular alignment of the femur head reflects the stress trajectory formed in resistance to manifold functional stresses. The stimulating influence of muscle or extra-functional force seems to produce demonstrable changes in bone. Thus the shape and internal structure of the femur head are related to lower extremity function. This theory is recognized as Wolff's law.

Harold T Perry Jr (1955)[27] studied the electrical activity of masseter and temporalis muscles using electromyography.

Melvin L Moss (1962)[58] suggested that maxillofacial morphology is controlled by development of function including nasal cavity or maxillary sinus and mandible is particularly influenced by masticatory muscle function, with final morphology being dependent upon masticatory muscle activity.

Melvin L Moss and Robin M Rankow (1968)[59] applied functional cranial analysis to study the growth of mandible in a bilateral condylotomy patient and suggested that even though the condylar cartilages are the main growth centers, the growth that occurs there is secondary and adaptive to the downward and forward translation of the mandible along with expansion of oro-facial capsule.

W R Proffit, J W Gamble and R L Christiansen (1968)[117] demonstrated generalized muscular weakening in severe anterior open bite after studying occlusal forces in normal and long face adults.

Melvin L Moss (1969)[60] applied functional cranial analysis to the mandibular angular cartilage of neonatal mice. Surgical removal of this secondary cartilage resulted in a normal mandible with growth. It was concluded that the angular cartilage plays no active role in growth of mandible and form, position and maintenance of angular process is secondary response to the primary morphogenetic demands of it's specifically related muscles.

V Sassouni (1969)[86] outlined the concept that vertical alignment (and subsequent force) of jaw-closing muscles directed skeletal growth toward a shallow mandibular plane angle, an acute gonial angle, and deep bite, whereas obliquely aligned jaw-closing muscles (with subsequent diminished force) permitted a steep mandibular plane, an obtuse gonial angle, and open bite.

Alonzo D Proctor, John P DeVinceto (1970)[3] showed a more horizontally placed masseter in skeletal open bite group compared to closed bite group relative to SN, Frankfurt and mandibular planes.

B Melsen (1975)[61] found that median suture of maxilla to fuse at the age of 16 in females and at 18 in males.

B Ingervall (1976)[33] studied the correlations between facial morphology and activity of the temporal muscle and the musculature of the lips electromyographically during swallowing and chewing. Upper lip activity was low in girls with small face height. Lower lip showed no correlation with facial form. Marked temporal muscle activity was noticed while swallowing in subjects with small face height.

B Ingervall and E Helkimo (1978)[34] studied the relationship between masticatory muscle force and facial morphology in man. The subjects with strong bite force differed from the weak in having an anterior inclination of the mandible with a smaller anterior and a greater posterior face height, a smaller gonial angle, a straighter cranial base and greater depth of the upper face, a tendency to parallelism between the mandibular occlusal line and the mandibular border as well as a broader maxilla. They concluded that form of the face partly depends on the strength of the muscles.

Gaylord S Throckmorton, Richard A Finn and William H Bell (1980)[95] presented a two-dimensional model which allows calculation of mechanical advantage of the human temporalis and masseter muscles. The model was manipulated to demonstrate how selected differences in facial morphology affected the mechanical advantage of the muscles and concluded that differences in facial morphology result in significant differences in the mechanical advantages of the muscles. They suggested that the mechanical advantage may, in part, explain observed differences in bite force.

Hans Pancherz (1980)[72] examined activity of the temporal and masseter muscles in Class II, Division 1 malocclusions. During maximal biting in intercuspal position the boys with Class II malocclusion exhibited less EMG activity in the masseter and temporal muscles than the boys with normal occlusion. In the Class II boys the reduction in EMG activity was most apparent for the masseter muscle. During chewing the Class II subjects showed less EMG activity in the masseter muscle than the normal occlusion subjects. For the temporal muscle, no differences were found between the two occlusion groups.

Robert M Beecher and Robert S Corruccini (1981)[83] studied the effects of dietary consistency in the craniofacial and occlusal development in rat. They suggested that the medio-lateral maxillary growth is dependent up on the hard particles in diet.

P Schantz, E Randall-Fox, W Hutchison, A Tyden, P O Astrand (1983)[87] examined the relationship between maximum voluntary concentric strength, muscle fiber type distribution and muscle cross-sectional areas. Maximal knee and elbow extension as well as elbow flexion torque at the angular velocities, 30, 90 and 180 degrees per second were measured. Muscle biopsies were taken from vastus lateralis and m. triceps brachii. The muscle cross-sectional area of the thigh and upper arm was measured with CT scanning. The maximal torque correlated strongly to the muscle cross-sectional area times an approximate measure on the lever arm. Maximal tension developed per unit of muscle cross-sectional area did not correlate significantly with percent Type I fiber area.

W R Proffit, H W Fields, and W L Nixon(1983)[75] evaluated occlusal forces using both quartz and foil-based piezo-electric force transducers, during swallowing, simulated chewing, and maximum effort in long-face and normal adults. Forces were measured at 2.5 mm and 6.0 mm molar separation. Long-face individuals were found to have significantly less occlusal force during maximum effort, simulated chewing, and swallowing than do individuals with normal vertical facial dimensions. No differences in forces between 2.5 and 6.0 mm jaw separation were observed for either group.

W R Proffit and H W Fields (1983)[76] simulated the same study in children from six to eleven years and found that forces of dental occlusion during swallowing, simulated chewing, and hard biting are similar for normal and long-face individuals. Forces in the normal and long-face children are similar to those in long-face adults, but are about half those in normal adults. They concluded that individuals with the long-face pattern fail to gain strength normally in the mandibular elevator muscles.

J E Hicks ,T H Shawker, B L Jones, M Linzer and L H Gerber (1984)[28] examined the use of Ultrasonography in the evaluation of skeletal muscle. They concluded that it is a non-invasive diagnostic aid which gives reliable and reproducible results.

Alan A Lowe and Kenji Takada (1984)[53] studied the association between anterior temporal, masseter, orbicularis oris activity and craniofacial morphology.

Kenji Takada, Alan A. Lowe and Vivien K. Freund (1984)[39] reported correlation between masticatory muscle orientation and dento-skeletal morphology in children.

W A Wejis and B Hillen (1984a)[109] performed the first study to assess the relationship between skull shape and masticatory muscle cross section. CT scans were used to measure the muscle thickness intersecting the thickest part of masseter, medial pterygoid, lateral pterygoid and temporalis muscles, right angle to the fiber direction. Skull shape and facial dimensions were assessed through anthropometry. The masseter and medial pterygoid muscles were large in persons with brachycephalic skulls (high cephalic index),short faces (low facial index) and a small jaw angle. The cross sectional areas of temporalis and lateral pterygoid muscles showed no correlation with facial dimensions.

W A Wejis and B Hillen (1984b)[110] Physiological cross-section and cross-sectional area in computer tomograms made at right angles to the mean fiber direction were compared in the masseter, temporalis and pterygoid muscles of six human cadavers. Statistically significant correlation was found between scan cross section and physiological cross-section. The scan cross section can be used to predict physiological cross-section, with an error of 0.3-1.0 cm^2.

W A Wejis and B Hillen (1985)[111] determined cross-sectional areas of the masseter, temporalis, medial pterygoid and lateral pterygoid muscles in male subjects with healthy dentitions by CT scans. The physiological cross-section of these muscles was predicted from the previously determined relationship between physiological cross-section and scan cross-sections. Strong correlations in cross-sectional area were only found between the masseter and medial pterygoid muscles while comparing with the cross sectional area obtained from cadavers.

W A Wejis and B Hillen (1986)[112] determined correlations between the cross-sectional areas of the jaw muscles measured in CT scans and a number of facial angles and dimensions measured from lateral radiographs. It appeared that the cross-sectional areas of temporalis and masseter muscles correlated positively with facial width. They concluded that the jaw muscles affect facial growth and partly determine the final facial dimensions.

Kathleen J Bolt and R Orchardson (1986)[36] studied relationship between mouth-opening force and facial skeletal dimensions in human females. Larger mouth-opening forces were associated with features characteristic of an angular facial profile, viz long mandibular base, short mandibular body and large gonial angle.

T Tauber, R Starinsky and D Varsano (1986)[93] used Ultrasonography and computed tomography for diagnosis of benign masseteric hypertrophy.

Surender K Nanda (1988)[69] examined the patterns of facial growth development in subjects with skeletal open-bite and skeletal deep-bite faces. It was established that the anterior dimensions of the face demonstrated typologically divergent patterns of development in open- and deep-bite faces. Further, the posterior dimensions of the face did not discriminate between these two typological groups. The female open-bite subjects were earliest in the timing of the adolescent growth spurt, followed in succession by deep-bite female subjects, open-bite male subjects, and finally the deep-bite male subjects.

P H Van spronsen, W A Weijs, J Valk, B Prahl-Andersen, and F C Van ginkel (1989)[99] determined cross-sectional areas of masseter, medial pterygoid and temporalis, by means of magnetic resonance imaging (MRI) in healthy adult male subjects. These findings were compared with the cross-sectional areas of the jaw muscles of the same subjects, obtained by means of computer tomography in the previous study (Weijs and Hillen, 1985). Significant correlations were found between the CT and MRI cross-sections of the masseter, medial pterygoid, and temporalis muscles. They concluded that compared with CT, MRI has some advantages, such as the absence of adverse effects (no radiation) and the excellent soft-tissue imaging. Furthermore, a series of frontal, horizontal, sagittal, and angulated MRI scans can be made without modification of the patient's position, facilitating reconstruction of the jaw muscles.

K Sasaki, A G Hannam, and W W Wood (1989)[85] studied relationships between the size, position, and angulations of human jaw muscles and unilateral first molar bite force. They concluded that craniofacial spatial morphology may differ among subjects; jaw muscle size alone seems to explain most of the variation in bite force.

A G Hannam and W W Wood (1989)[25] studied the relationships between the size and spatial morphology of human masseter and medial pterygoid muscles obtained with MRI, the craniofacial skeleton, and jaw biomechanics. The potential abilities of the muscles to generate bite forces at the molar teeth and mandibular condyles were calculated according to static equilibrium theory using muscle, first molar, and condylar moment arms. On average, the masseter muscle was about 66% larger in cross section than the medial pterygoid and was inclined more anteriorly relative to the functional occlusal plane. The masseter muscle was always a more efficient producer of vertically oriented bite force than the medial pterygoid. There was a significant positive correlation between the cross-sectional areas of the masseter and medial pterygoid muscles and between the bizygomatic arch width and masseter cross-sectional area and medial pterygoid cross-sectional area.

G E Langenbach, Weijs W A (1990)[49] examined the post-natal growth of the masticatory muscles in the rabbit between one week and 36 months. By means of anatomical dissection and measurement, total muscle length, muscle fiber length, and muscle weight were determined. The study demonstrated that individual oral muscles follow different patterns of longitudinal and cross-sectional growth, so that their functional capacities (force, range of contraction) and mutual functional relationships are age-dependent.

P H Van spronsen, W A Weijs, J Valk, B Prahl-Andersen, and F C Van ginkel (1991)[100] studied the relationships between jaw muscle cross-sections and craniofacial morphology in normal adults, with MRI. Positive significant correlations were found between a linear combination of several transversal skull dimensions on one hand, and the maximal temporalis and masseter cross-sections on the other. A negative significant correlation was found between the flexure of the cranial base and the temporalis cross-section. No significant correlations were found between either anterior facial height or posterior facial height and any of the jaw muscles cross-sections. It was concluded that, in adult males with normal skull shape, relationships exist to a limited extent between craniofacial morphology and the cross-sectional areas of the jaw muscles.

S J Lindauer, T Gay and J Rendell (1991)[50] examined electromyographic force characteristics in the assessment of oral function. Masseter-muscle activity was recorded during controlled isometric biting exercises performed at various bite openings and force levels on two separate occasions. They concluded that acceptable reliability and sensitivity of quantitative EMG values can be achieved, especially at higher muscle-activity levels, by rigidly controlling and quantifying functional activities during experimental trials; the slope of an EMG-force curve is a reproducible, quantitative, and functionally sensitive measurement for assessment of muscle function.

S Kiliaridis and P Kalebo (1991)[40] evaluated Ultrasonography as a method for measuring masseter muscle thickness. Ultrasonography was found to be a reliable and accurate method for study of the thickness of the masseter muscle. The measurement error of the thickness of the masseter was found to be small, not exceeding 0.49 mm. In 40 healthy, fully-dentate young adults, 20 men and 20 women, the masseter thickness was measured bilaterally by a real-time ultrasound imaging technique. The measurements were performed under both relaxed conditions and with maximal clenching. The thickness of the masseter muscle was found to be related to the facial morphology, mainly in women, but not in men; the women with a thin masseter had a proportionally longer face. There was a large variation in the thickness of the muscle between individuals, and the thickness of the masseter was related to facial morphology in women. Anthropological caliper measurements proved more reliable than standardized digital photographs for evaluating facial morphology.

T M van Eijden and M C Raadsheer (1992)[105] studied the regional differences in the architectural design of the human masseter muscle. It was concluded that, due to heterogeneity in fiber and sarcomere lengths, the distribution of maximal isometric tension across the muscle at full effort is not uniform.

P H Van spronsen, W A Weijs, J Valk, B Prahl-Andersen, and F C Van ginkel (1992)[101] compared the mid-belly cross-sectional areas of the jaw muscles of long-face and normal adults by means of serial MRI scans. The subjects were selected on the basis of anterior lower face height as a percentage of anterior total face height as measured from lateral radiographs. In the long-face group, the cross-sectional areas of the masseter, medial pterygoid, and anterior temporal muscles were, respectively, 30%, 22%, and 15% smaller than in the control group. The findings of this study hint that, differences in the sizes of the jaw muscles of long-face and normal subjects might explain, in part, the observed differences in maximum molar bite force.

M Bakke, A Tuxen, P Vilmann, B R Jensen, A Vilmann, M Toft (1992)[4] examined the ultrasound image of human masseter muscle related to bite force, electromyography, facial morphology, and occlusal factors. Ultrasonography produced a well-defined depiction of the muscle with distinct tendinous structures according to them. The study showed a connection between measures of masseter thickness and function of the muscle. Muscle thickness at the voluminous anterior part of the superficial portion was systematically and significantly correlated to bite force, occlusal tooth contact and anterior face height, vertical jaw relation and mandibular inclination evaluated from cephalograms. They concluded that, ultrasound scanning gave an uncomplicated and a reproducible access to parameters of jaw muscle function and its interaction with the cranio-mandibular system.

J Varrela (1992)[108] studied the dimensional variation of craniofacial structures in relation to changing masticatory-functional demands. He examined two Finnish samples, one exposed to a hard and the other to a soft diet, cephalometrically. The samples comprised skulls, derived from the 16th and 17th centuries, and living individuals. In the present-day sample, the cranial length and the anterior cranial base were significantly longer, and the upper incisors segment significantly higher. In the skull sample, the posterior facial height, the height of the mandibular ramus, and the antero-posterior width of the pharynx were significantly larger. He concluded that hard diet, which requires more chewing force and time, promotes vertical growth of the ramus and anterior translocation of the maxilla.

Stephen F Snodell, Ram S Nanda and G Fräns Currier (1993)[90] carried out a longitudinal cephalometric study of transverse and vertical craniofacial growth. Growth for males continued past age 18 years for all skeletal measurements, except for maxillary width. Growth for females was completed by 17 years for all skeletal measurements. Facial width was correlated to cranial width and maxillary width in females. Also the inter-molar width in maxillary arch was correlated with maxillary width.

S Kiliaridis, H Kjellberg, B Wenneberg and C Engstrom (1993)[41] studied the relationship between maximal bite force, and facial morphology in growing individuals. Subjects with a high bite force had a relatively short lower anterior face height.

S E Menapace, D J Richuse, T Zullo, C J Pierce, and H Shnorhokian (1994)[92] studied the dento-facial morphology of bruxers and non-bruxers and concluded that there is no statistically significant differences in the craniofacial morphology of bruxers and non bruxers.

M C Raadsheer, T M van Eijden, F C van Ginkel, S Kiliaridis and B Prahl-Andersen (1994)[77] compared human masseter muscle thickness measured by Ultrasonography and magnetic resonance imaging. Comparisons were made from measurements taken from serial MRI scans and Ultrasonography at three different levels. The conclusion is that Ultrasonography is an accurate and reproducible method for measuring the thickness of the masseter *in vivo*.

Ultrasonography allows for large-scale longitudinal study of changes in jaw-muscle thickness during growth in relation to change in biomechanical properties of masticatory muscles.

S Ruf, H Pancherz and M Kirschbaum (1994)[84] probed the relationship of masseter muscle size and activity to facial morphology. The interrelationships between masseter muscle activity and size and facial morphology were generally weak ; the links were more discernible in the women than in the men. Female subjects with thin faces and large mandibular planes had reduced masseter thickness.

L L Foglel and A G Glaros (1995)[22]scrutinized the hypothesis that facial morphology variables contribute significantly and meaningfully to the variance in masticatory muscle EMG when subjects produce specific levels of inter-occlusal force, but not when subjects are at rest. A canonical correlation analysis, performed on the set of predictor variables (age, gender, and facial morphology measurements) and the set of criterion variables (EMG data), showed a significant canonical correlation between the two variable sets while biting, but not at rest. The data suggest that facial morphology variables examined in this study do not exert a meaningful influence on EMG data.

P J Close, M J Stokes, L Estrange, J Rowell (1995)[14] examined the relationship between linear dimensions of human masseter muscle cross-section and cross-sectional area and to assess symmetry between the two sides in normal young adults. All correlation values between cross-sectional area and linear measurements were significant but muscle cross-sectional area was most accurately predicted when the linear measurement was multiplied. Although the correlation in this regard was high, the linear dimension consistently overestimated the actual cross-sectional area by approximately 25%. Masseter cross-sectional area was larger in males than in females. Males showed more symmetry of cross-sectional area than females.

K Miyamoto, K Yamada, Y Ishizuka, N Morimoto, and K Tanne (1996)[63] examined masseter muscle activity during the whole day in young adults. Most of the strong bursts of the masseter muscle appeared only during meals and a number of low amplitude bursts were observed during the entire day, although masseter muscle activity during the entire day in young adults was less than expected. They concluded that exercise for masticatory muscles might be necessary for people with low bite forces and this may in turn influence the facial morphology.

P H van Spronsen, W A Weijs, F C van Ginkel, and B Prahl-Andersen(1996)[102] studied the jaw muscle orientation and moment arms of long face and normal adults. They concluded that the variation of the spatial orientation of the jaw muscles is small and does not significantly contribute to the explanation of the different molar bite-force levels of long face and normal subjects.

M C Raadsheer, T M van Eijden, F C van Ginkell, S Kiliaridis and B Prahl-Andersen (1996)[78] examined masseter muscle thickness in growing individuals and its relation to facial morphology. Masseter muscle thickness increased with age in both sexes. No differences were found between the left- and right-hand sides. For each age group, males had significantly thicker masseter than females. Apart from these, muscle thickness showed a significantly negative relation with anterior facial height and mandibular length, and a significantly positive relation with inter-gonial width and bizygomatic facial width.

S Yamamoto (1996)[114] studied the effect of food consistency on maxillary growth in rats. He proposed that the difference in the growth pattern in the upper viscerocranium induced by different food consistencies is caused not only by a difference in mechanical force of the masticatory muscles acting on the muscle insertion areas but also by a difference in the growth pattern in the region which receives occlusal loading.

P Pirttiniemi and T Kantomaa (1996)[73] examined the effect of electrical stimulation of masseter muscle on the condylar morphology of the masseter muscles of mice. Explants were stimulated with alternating current with frequency of 0.7 Hz and amplitude of 5V. They concluded that the muscular function in the stimulated group remodels the morphology of condyle into a fundamentally altered form which can be seen as a consequence of active growth induced by functionally limited joint movement.

P H van Spronsen, J H Koolstra, F C van Ginkel, W A Weijs, J Valk and B Prahl-Andersen (1997)[103] studied the relationships between the orientation and moment arms of the human jaw muscles and normal craniofacial morphology. The anterior face height factor was significantly correlated with the orientation of the jaw opening muscles in the sagittal plane but was not significantly correlated with the orientation of the mandibular elevators. The sagittal moment arms of the mandibular elevators showed significant correlations with the factors describing the gonial angle and the posterior face height. It was concluded that the variation of spatial orientation of the human jaw closing muscles is predominantly associated with the variation of mandibular morphology (expressed by the gonial angle) and the posterior face height. The hypothesis that persons with an increased anterior face height have relatively oblique orientated jaw elevators was rejected.

W A Wejis (1997)[113] studied the functional properties of the masticatory muscle fibers and concluded that the fibers of jaw muscle motor units often belong to different fiber types, with four different kinds of myosin heavy chain (MHC). For this reason, the units cannot be subdivided into clear-cut types, but show a continuous range of contraction times.

N. Kitai, Y Fujii, S Murakami, S Furukawa, S Kreiborg and K Takada (1997)[46] tested the hypothesis that masticatory muscle volume correlates with the size and form of the adjacent local skeletal sites. They investigated the morphological association of the cross-sectional area and volume of temporal and masseter muscles with zygomatico-mandibular skeletal structures using computerized tomography (CT) in male adults with mandibular prognathism. Masseter volume significantly correlated with cross-sectional areas of the zygomatic arch and mandibular ramus. Masseter orientation was almost perpendicular to the zygomatic arch and mandibular antegonial region. The zygomatic arch angle significantly correlated with the antegonial angle.

B Ingervall and C Minder (1997)[35] studied the correlation between maximum bite force and facial morphology in children and found large bite forces in females with low anterior facial height and small mandibular inclination and gonial angle. These correlations were weak in boys.

S J Lindeuer (1997)[51] suggested that substantial variation in bite force and muscle function remain largely unexplained by differences in facial morphology. He proposed that it could be due to variation in occlusal contacts.

S E Bishara, J R Jakobsen, J Treder, A Nowak (1997)[8] observed arch width changes from 6 weeks to 45 years of age. Maxillary inter-molar width increased significantly in both sexes between 3 and 13 years of age, after which it remains stable in males, whereas it decreased slightly in females. Males were found to have a significantly larger maxillary inter-molar width than females in all age groups.

S Kiliaridis and C Katsaros (1998)[42] studied the effects of Myotonic dystrophy and Duchenne muscular dystrophy on the orofacial muscles and dento-facial morphology. The vertical aberration of their craniofacial growth in Myotonic dystrophy patients is strongly related to the involvement of the masticatory muscles in association with the possibly less affected supra-hyoid musculature. Decreased width of the palate and causing posterior cross-bite is seen along with lowered tongue position. The lowered position of the mandible, in combination with the decreased biting forces, lead to over-eruption of the posterior teeth, with increased palatal vault height and development of anterior open-bite. On the contrary, the posterior cross-bite in Duchenne muscular dystrophy is due to the transverse expansion of the mandibular arch, possibly because of the decreased tonus of the masseter muscle near the molars, in combination with the enlarged hypotonic tongue and the predominance of the less affected orbicularis oris muscle.

T Ono, Y Ishiwata, and T Kuroda (1998)[71] examined how oral respiration affects the activity of the jaw-closing muscles. Their EMG findings on cat suggest that masseteric electromyographic activity is inhibited during oral respiration.

H M Ueda, Y Ishizuka, K Miyamoto, N Morimoto and K Tanne (1998)[97]investigated the relationship between masticatory muscle activity and vertical craniofacial morphology. Surface electrodes were kept on the subjects for 3 hours during day time to record the EMG activity of masseter, temporalis and digastric muscles. It was found that the muscle activities mainly consisted of low amplitude bursts. Masseter and digastric activities showed significant negative correlation with vertical craniofacial morphology whereas temporalis activity was positively correlated.

J Fanghanel, B Miehe, D K Miesenburg, H Nagerl and R S Polly (1998)[20] attempted to study the relationships between masticatory muscles and occlusal relationship by

bilateral extraction of supporting teeth in wister albino rats. They noticed a significant reduction in the muscle dry weight most noticeably in the masseter. There was a decrease in mitochondria rich fast fibers and an increase in mitochondria poor slow fibers.

N P Hunt, Z N Moon, I S Tan, M Lewis and A J A Madgwick (1998)[30] studied the histo-chemical changes in masseter muscle in long face patients. They tried to ascertain whether the reduced fast fibers in the muscle are secondary to the facial morphology or is the primary etiology. They concluded that the structural changes in the masseter are due to primary myopathy than a reflection of functional requirements.

S Kiliaridis and C M Mills (1998)[43] examined the masseter muscle thickness before and after twin block therapy and found that decreased functional activity had lead to mild atrophy of the masseter.

M J Morgan, S C Brown and A J A Madgwick (1998)[65] studied the FHL mRNA expression in the masseter muscle of dystrophic mice. They found elevated expression of FHL-1 and FHL-3 in skeletal muscles versus other tissues and high expression of FHL-3 in masseter muscle. This is the histological evidence for masseter being involved in the disease.

N L Price, M P Lewis and N P Hunt (1998)[74] investigated the expression of mRNA coding for fibro-nectin and its spliced variants EIIIA and EIIIB in the masseter of patients with vertical facial deformity of developmental origin. They found fibro-nectin *mRNA* containing EIIIA exon. Fibro-nectin deposition increases in muscular dystrophies in which progressive increase in facial height is often noted.

M Kabota, H Nakano, I Sanjo, K Satoh, T Sanjo, T Kamegai and F Ishikawa (1998)[67] investigated the relationship of the thickness of masseter muscle obtained by Ultrasonography to facial morphology variables, including the thickness of mandibular symphysis, in males. Masseter thickness negatively correlated with the mandibular plane angle and positively correlated with the ramus height and thickness of mandibular symphysis.

H Matsushima, K Nakano, K Matsushima, Y Seino, T Kamegai (1998)[57] examined the relationship between masticatory muscle volume and size and shape of jaw bones. Height of the mandibular ramus and height of the body at the molar region correlated with medial pterygoid volume. Positive correlation between masseter volume and masseter thickness was also seen.

M C Raadsheer, T M van Eijden, F C van Ginkell, and B Prahl-Andersen (1999)[79] studied the relative contributions of craniofacial morphology and jaw muscle thickness to the bite force magnitude. Only the thickness of the masseter muscle correlated significantly with bite force magnitude. Bite force magnitude also correlated significantly positively with vertical and transverse facial dimensions and the inclination of the mid-face, and significantly negatively with mandibular inclination and occlusal plane inclination. They concluded that the contribution of the masseter muscle to the variation in bite force magnitude was higher than that of the craniofacial factors. Also measurement errors of anthropologic measurements were found to be similar to cephalometric ones.

Philips C M Benington, John E Gardener and Nigel P Hunt (1999)[6] estimated masseter muscle volume with 3-D Ultrasonography and studied its relationship with facial morphology. Masseter muscle volume showed significant negative correlation with mandibular inclination including gonial angle. Significant positive correlation was shown with total posterior facial height and ramus height.

H M Ueda, K Miyamoto, Saifuddin, Y Ishizuka and K Tanne (2000)[98] examined the relationship between the duration of masticatory muscle activity during daytime and vertical craniofacial morphology in children and adults. The activities of masseter and digastric muscles were significantly related with the vertical facial type in both children and adults.

C Katsaros (2001)[37] studied the influence of reduced masticatory muscle function on the transverse dimensions of the pre-maxilla, maxilla (including the dental arch) and the calvaria was on dry skulls of rats which were fed soft diet. The relationship between maxillary dental arch width and masseter muscle thickness in humans were studied using Ultrasonography. Masticatory muscle function was found to influence the transverse growth of the skull at areas under direct muscle influence as well as the dental arch width in regions with molars under eruption. The dimensions and morphology of the facial sutures as well as the sutural bone apposition were negatively affected by reduced masticatory function. They concluded that this could be one of the underlying mechanisms of the clinical finding that subjects with thicker masseter muscles were found to have a broader maxillary dental arch.

M N Spyropoulos, A I Tsolakis, C Alexandridis, E Katsavrias and I Dontas (2002)[91] examined the influence of the supra-hyoid muscles on mandibular growth, morphology, and orientation. Bilateral supra-hyoid muscle myectomy was done on four week old rats for this purpose. Occurrence of decreased mandibular growth and a more upward orientation of mandible lead them to conclude that supra-hyoid muscles play an important role in facial growth.

C Katsaros, R Berg and S Kiliaridis (2002)[38] studied the influence of masticatory muscle function on transverse skull dimensions in the growing rat. Animals were randomly divided into two equal groups; one received the ordinary diet in hard pellet form, and the other a soft diet. The dental arch was found to be narrower in the third molar region in the soft diet group, possibly due to less growth in the mid-palatal suture and/or to reduced occlusal loading. Furthermore, the pre-maxilla and the frontal bones at the most lateral part of the temporal crest were narrower in the soft diet group, these regions being areas of masticatory muscle attachment.

S Kiliaridis, I Georgiakaki and C Katsaros (2003)[45] investigated the relationship between the ultrasonographic thickness of the masseter muscle and the width of the maxillary dental arch. Inter-molar width showed no association with age and gender. The masseter muscle was thicker in older individuals and in males. In the female group, maxillary inter-molar width showed a direct, significant association with masseter thickness both during contraction and relaxation, i.e. females with thicker masseter muscles had a wider maxillary dental arch. In the male group, however, no significant relationship was found between maxillary inter-molar width and masseter thickness. They suggested that the functional capacity of the masticatory muscles may be considered as one of the factors influencing the width of the maxillary dental arch.

C J Lux, C Conradt, D Burden and G Komposch (2004)[55] studied transverse development of the craniofacial skeleton and dentition between 7 and 15 years of age using longitudinal postero-anterior cephalograms. Most of the craniofacial widths were larger in males than in females. The majority of the skeletal dimensions showed a progressive increase in width. In contrast, there was a deceleration in the increase in maxillary and mandibular inter-molar widths after 11 years of age in males and even a slight decrease in the inter-molar width beyond 11 years of age in females. It was also shown that by the age of 7 years, over 95 per cent of the growth in the inter-molar width had occurred.

L Sonnesen and M Bakke (2005)[52] studied molar bite force in relation to occlusion, craniofacial dimensions, and head posture in pre-orthodontic children. The maximum bite force increased significantly with age in girls, with teeth in occlusal contact in boys, and with increasing number of erupted teeth in both genders. Multiple regression analysis showed that the vertical jaw relationship and the number of teeth present were the most important factors for the magnitude of bite force in boys. In girls, the most important factor was the number of teeth present . No correlations between bite force and head posture were found in this study.

A Rowlerson, G Raoul, Y Daniel, J Close,C A Maurage, J Ferri and J J Sciote (2005)[115] studied the fiber-type differences in masseter muscle associated with different facial morphologies in orthognathic surgery patients. Type I (slow) fiber occupancy increased in open bites, and conversely, Type II (fast) fiber occupancy increased in deep bites.

MATERIALS AND METHODS

SUBJECT SELECTION CRITERIA

The sample of the present study comprised of 25 volunteer female dental students, 21-23 years of age, from Tamilnadu Govt Dental College and Hospital. The mean age of the subjects was 22.2 years.

In an attempt to exclude factors that might influence maxillary dental arch width or muscle thickness, only those with a Class I occlusion with full complement of dentition with/without erupted third molars were selected. The subjects had no history of pain in the masticatory muscles or temporo-mandibular joint. Due care was exercised to avoid cases of functional problems, cross-bites, and bruxism. From a medical point of view, subjects had no history of neuromuscular or joint disease or systemic illnesses that might affect neuromuscular system.

MEASUREMENT OF MASSETER MUSCLE THICKNESS

The thickness of the masseter muscle was measured by the same operator, using a real time scanner (**ALOKA Prosound, SSD-3500,** Japan) with a 7.5 MHz linear array transducer. The investigation was carried out from Barnard Institute of Radiology, GGH, Chennai. The participants were seated in an upright position with their heads in a natural position. A generous amount of gel was used under the probe to avoid tissue compression. The measurement site was at the thickest part of the masseter close to the level of the occlusal plane, halfway between the zygomatic arch and gonial angle, approximately at the centre of the medio-lateral distance of the ramus. Since oblique scanning exaggerates the thickness of the muscle, care was taken to orient the transducer perpendicular to the ramus. Recordings were performed bilaterally with the muscles during both relaxation and maximal clenching in the intercuspal position. The measurements were made directly from the image with a read out distance of 0.1 mm. This is very similar to the method of **Kiliaridis and Kälebo**[40,45].

Three measurements were taken each time and the intermediate reading of the three was considered to be the actual thickness and was recorded. The measurements were repeated if more than 0.4 mm difference were found between the largest and smallest value. The mean thickness of the left and right side was taken as the final measurement.

ANTHROPOMETRY

Spreading caliper was used to take anthropological measurements (Photoplate –II). Maximum cranial length was determined by measuring the distance between glabella (most prominent point in the median sagittal plane between the supraorbital ridges) and opisthocranion (farthest projecting point of the mid-sagittal plane on the back of the head). Maximum cranial breadth was measured at euryon, i.e, the greatest transverse diameter of the head at the most lateral projecting point over each parietal bone (Photoplate –III).The Cephalic Index was calculated using the formula:

Cephalic Index = (Maximum cranial breadth / Maximum cranial length) × 100

Nasion was designated as the soft tissue point at which the most anterior point of the fronto-nasal sutures intersect the mid-sagittal plane, with the subject looking straight ahead.

Gnathion was located as the lowest median point on the lower border of the mandible. Bizygomatic breadth was designated by the distance between the most laterally situated points on the zygomatic arches (Zygion) (Photoplate –III). The Facial Index was calculated using the formula:

Facial Index = (Nasion-Gnathion Height / Bizygomatic breadth) × 100

Intergonial width is designated as the distance between gonion on one side to the other [92]. The Gonial Index was calculated using the formula:

Gonial Index = (Intergonial width / Bizygomatic breadth) × 100

No attempt was made to detect the facial type or head form. All measurements were obtained by same operator.

CEPHALOMETRY

The maxillofacial morphology was investigated with lateral roentgenographic cephalometry. Radiographs were taken from Chandru Specialty Dental X-rays, Chennai. Cephalograms were hand traced and landmarks identified (Figure-I). Seven linear, six angular and two proportional variables were analyzed.

Linear measurements: (Figure-II)

1.Cd (Condylion)-Go (Gonion) --Ramus Height

2.Go (Gonion)-Me (Menton) --Corpus Length

3.S (Sella)-N (Nasion) --Cranial Base Length

4.LAFH --Lower anterior facial height

5.LPFH --Lower posterior facial height

6.TAFH --Total anterior facial height

7.TPFH --Total posterior facial height

Angular measurements: (Figure-III)

1.SNA

2.SNB

3.ANB

4.Gonial angle

5.Mandibular plane angle

6.Ramus inclination

Proportional measurements:

1.LAFH (Lower anterior facial height)/TAFH(Total anterior facial height)

2.LPFH (Lower posterior facial height)/TPFH(Total posterior facial height)

MAXILLARY INTER-MOLAR WIDTH

Maxillary inter-molar width was measured with divider as the distance between the palatal surfaces of the first permanent molars on the casts obtained from subjects. The smallest possible distance was always recorded.

SOURCES OF ERROR

The measurement error estimation was done through Dahlberg formula. The errors of measurement (Se) and the anthropometric and cephalometric measurements were assessed on repeated measurements (m^1, m^2) of 5 randomly selected participants (n), according to the formula:

$$Se = \sqrt{\frac{\sum (m^1 - m^2)^2}{2 \times n}}$$

The anthropometric errors were 3.8 mm or less; the cephalometric linear measurements errors were 0.9 mm or less and angular measurements errors were 1.5 degrees or less. The error for masseter thickness was small, not exceeding 0.4 mm in relaxation and 0.3 mm during contraction, whereas the error for the maxillary inter-molar width was found to be 0.4 mm or less.

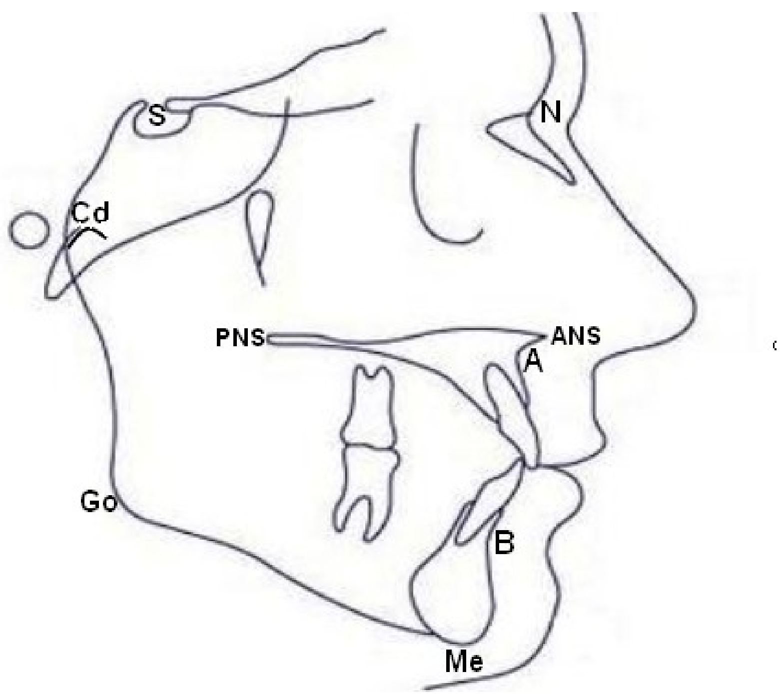
STATISTICS

Pearson's correlation coefficients were determined to appraise the strength of relationship between masseter muscle thickness in the relaxed and contracted states and the other variables including inter-molar width.

To examine the dependency of the muscle thickness on other variables, a simple regression analysis was done with muscle thickness as the dependent variable and the facial morphology variables, including inter-molar width as independent variables.

To detect the effects of independent variables on the dependent variable (masseter muscle thickness), stepwise multiple regression analysis was carried out. SPSS package, (SPSS inc) software was used for statistical analysis.

Figure – I



The following cephalometric landmarks were used in the study :

1. **ANS (Anterior nasal spine):** The anterior tip of the sharp bony process of maxilla at the lower margin of anterior nasal opening**.**

2. **Cd (Condylion):** Most superior point on head of condyle.

3. **Go(Gonion):** A point on the curvature of angle of the mandible located by bisecting the angle formed by lines tangent to posterior ramus and inferior border of the mandible.

4. **Me (Menton):** Lowest point on the symphyseal shadow of the mandible seen on the lateral

cephalograms.

5. **N (Nasion):** Most anterior point on the fronto-nasal suture in the mid-sagittal plane.

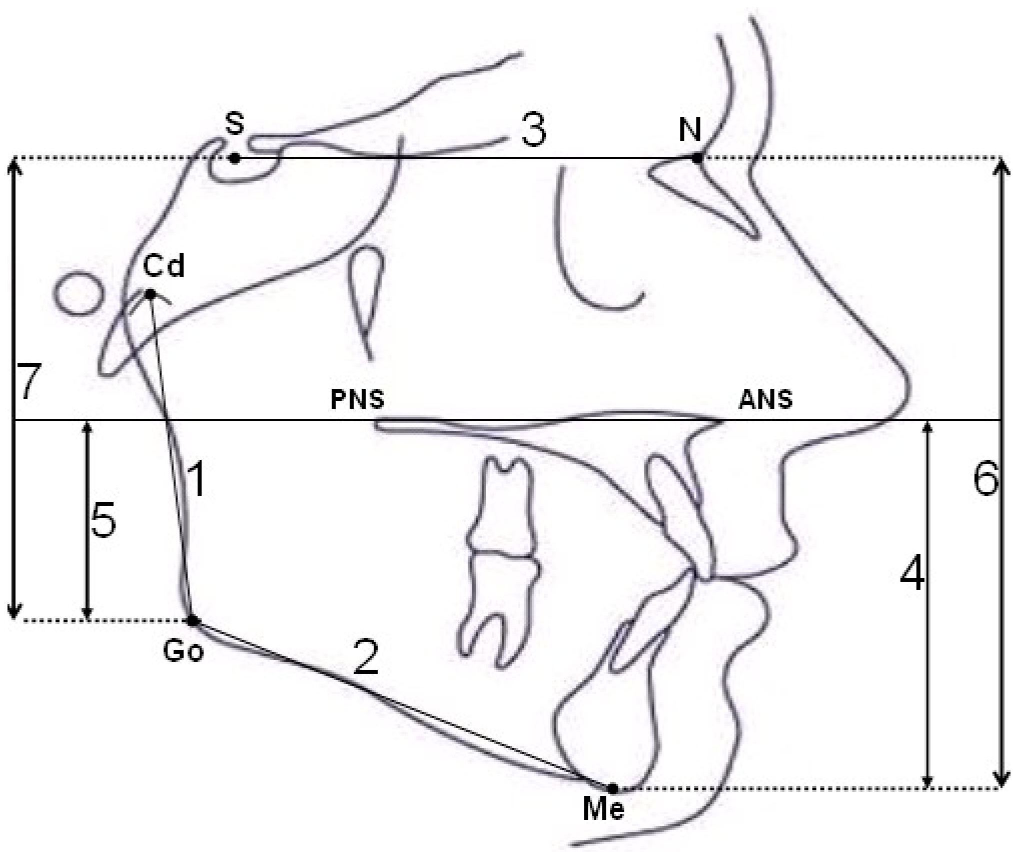
6. **PNS (Posterior nasal spine):** Posterior spine of the palatine bone constituting the hard palate.

7. **Point A (Subspinale):** The most posterior midline point in the concavity between anterior nasal spine and the most inferior point on the alveolar bone overlying the maxillary incisors.

8. **Point B (Supramentale):** The most posterior midline point in the concavity of the mandible between the most superior point in the alveolar bone overlying lower incisors and most anterior point of chin.

9. **S (Sella):** The midpoint of hypophyseal fossa.

Figure – II

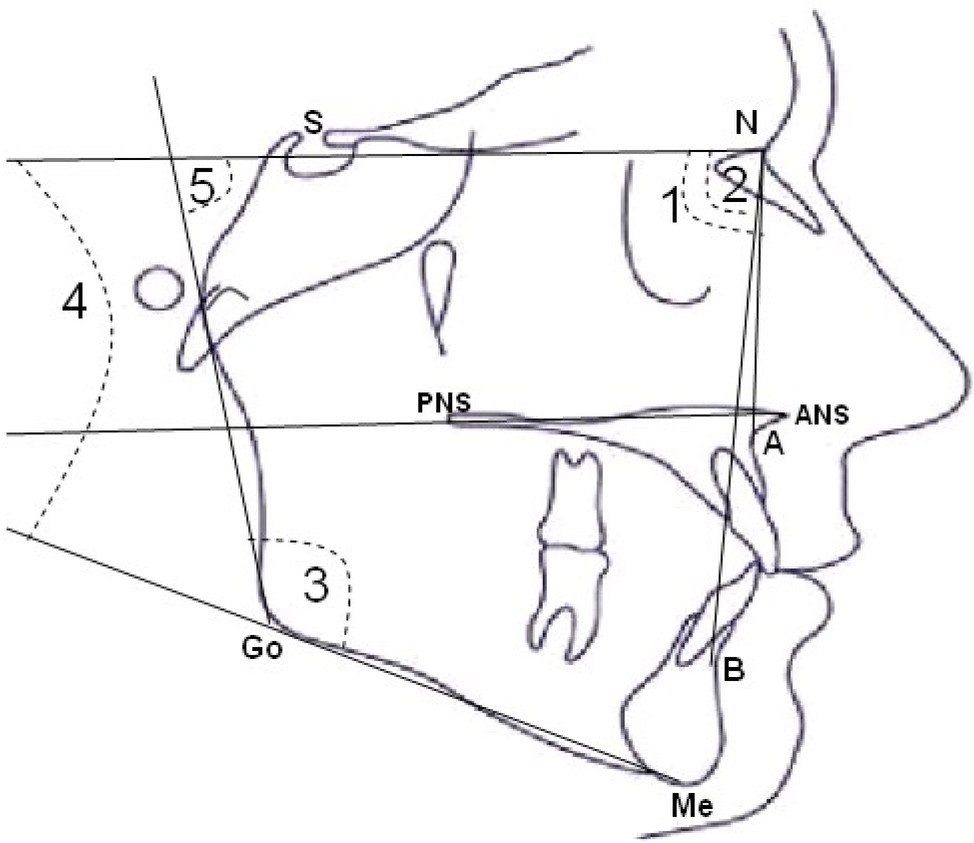


Linear measurements from lateral cephalogram :

1. Cd (Condylion)-Go (Gonion) --Ramus Height
2. Go (Gonion)-Me (Menton) --Corpus length
3. S (Sella)-N (Nasion) --Cranial Base Length

4. LAFH --Lower anterior facial height
5. LPFH --Lower posterior facial height
6. TAFH --Total anterior facial height
7. TPFH --Total posterior facial height

Figure - III



Angular measurements from lateral cephalogram :

1. SNA
2. SNB
3. Gonial angle (CdGo to GoMe)
4. Mandibular plane angle (SN to GoMe)
5. Ramus inclination (ramus tangent to SN)

PHOTOPLATE - I

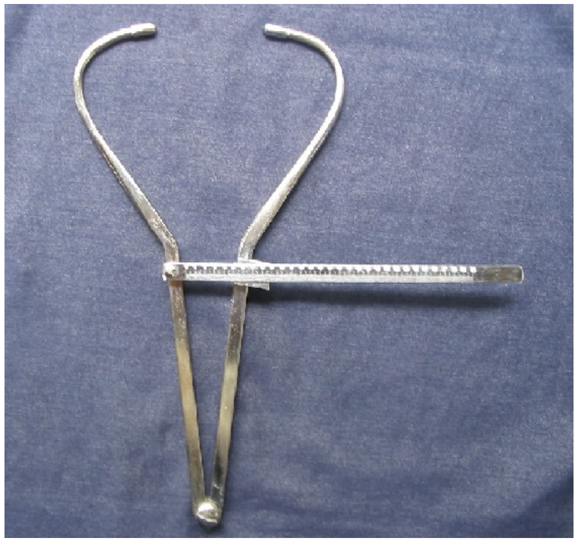
a) Ultrasonographic Image of Relaxed Masseter

b) Ultrasonographic Image of Contracted Masseter

PHOTOPLATE – II

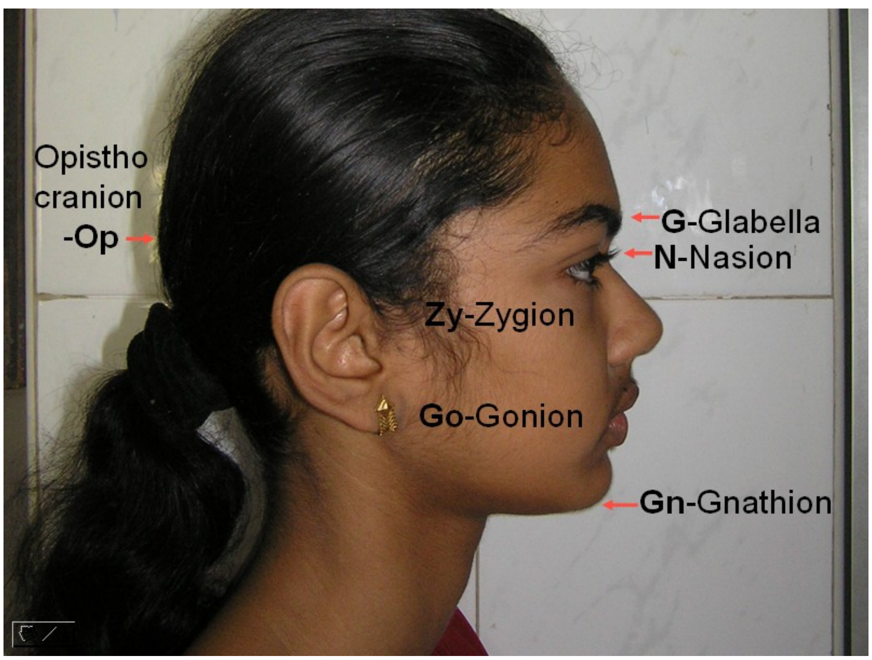
a) ALOKA Prosound,SSD-3500,Real time scanner used for Ultrasonography

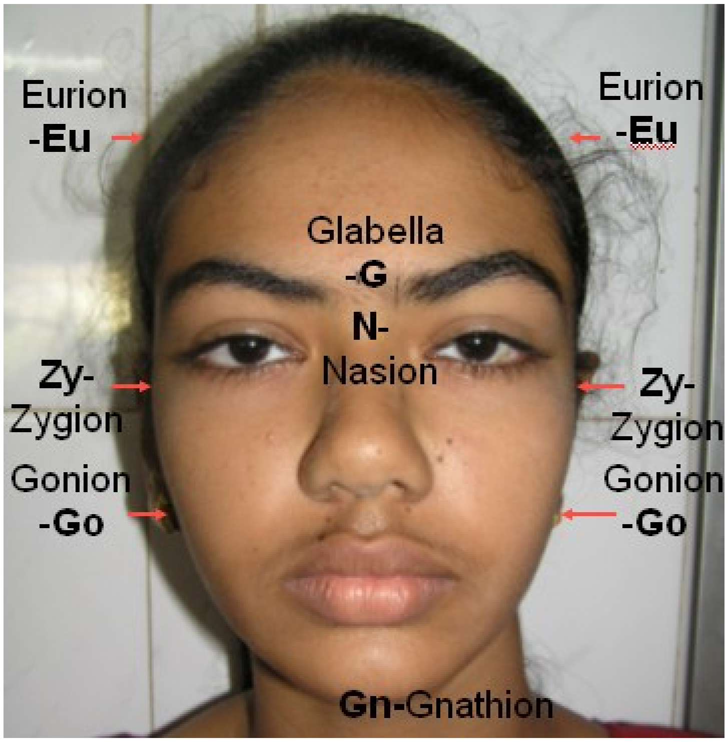
b) Spreading Anthropological caliper



PHOTOPLATE - III

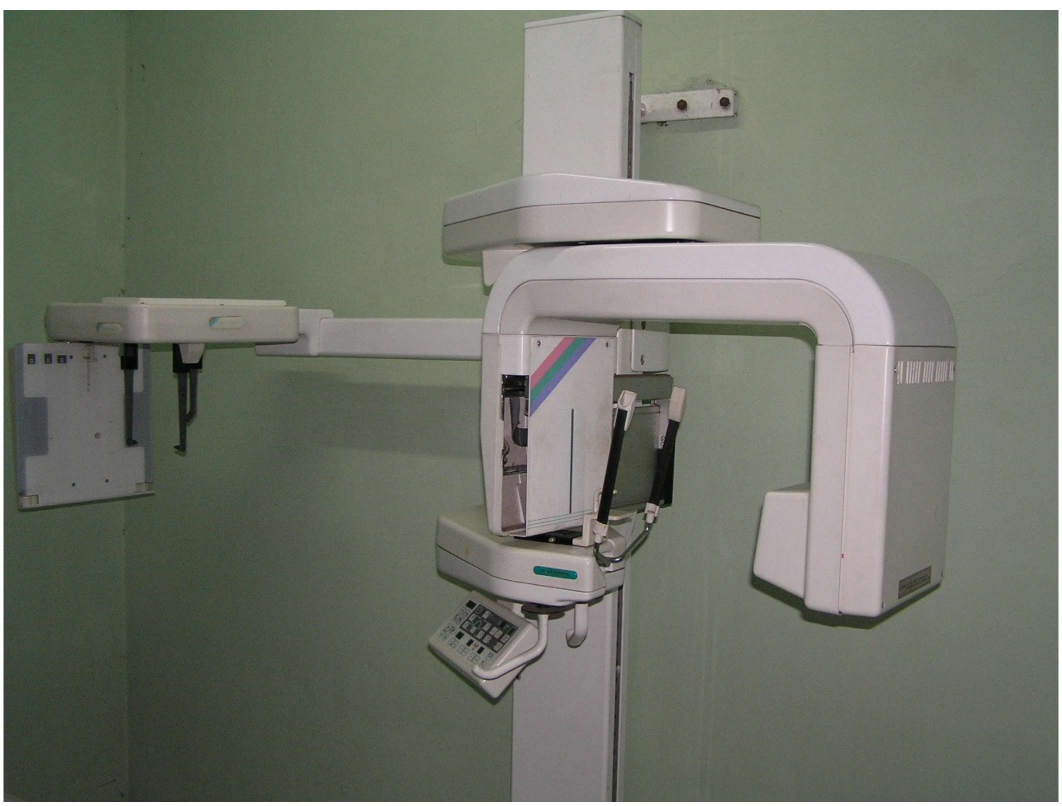
Anthropological landmarks





PHOTOPLATE – IV

Cephalostat



RESULTS

Statistically significant positive correlations were seen between thickness of masseter muscle in the relaxed state and intergonial width, inter-molar width and body weight. Masseter muscle in the contracted state showed significant correlations with intergonial width, bizygomatic width and total posterior facial height (Table-II). The associations are visualized in the form of scatter charts 1-6 (page 51-53). The relationship between masseter muscle thickness in the relaxed and contracted states (dependent variable) and the facial morphology variables were very similar in Simple regression analysis to the Pearsons method (Table-III).

Multiple regression analysis showed highly significant relationship between relaxed masseter thickness (dependent variable) and inter-molar width and mandibular plane angle (independent variables). Masseter thickness in the contracted state was also significantly dependent on the same independent variables. Predictive equations were derived using the statistically significant variables for masseter muscle thickness in relaxed and contracted states. (Tables-V&VI)

INTERPRETATION OF THE RESULTS

The Pearson's correlation coefficient (**r**) is the index of extent to which two variables are associated. **r** = 0.440; when the two variables compared are, thickness of the masseter muscle in the relaxed state and inter-molar width (Table-II). There is a positive linear association between the two variables. The association can be said to be weak (**r** = 0.2-0.5)[66] . As the masseter thickness increases inter-molar width also increases. But it does not mean that increase in masseter thickness causes increase in inter-molar width. Increases in both can be caused by a third variable[118].

While correlation analysis assumes no causal relationship between variables, simple regression analysis assumes that one variable is dependent upon another single independent variable. It is used to arrive at a predictive equation. According to Table-IV, Masseter muscle thickness in the relaxed state (**y**) is dependent upon the inter-molar width (**x**) according to the following equation :

$\mathbf{y} = -0.536 + 0.249\,\mathbf{x}$, when -0.536 is the constant and 0.249 is the slope coefficient. The interpretation is that; for every mm increase in inter-molar distance there could be 0.249 mm increase in masseter thickness in the relaxed state. $\mathbf{R^2}$ value of 0.193 indicates that over 19 % variability in the masseter muscle thickness can be explained by variability in inter-molar width.

Multiple regression analysis is a tool with which dependency of a variable on a set of independent variables can be assessed. The slope coefficient (**b**) recorded by each independent variable (Table-V), indicate the effect of that variable on dependent variable when all other variables are held constant. Relaxed masseter muscle thickness (**y**) is related to independent variables inter-molar width **(xa)** and mandibular plane angle **(xb)** in the following manner.

$\mathbf{y} = 3.052 + 0.071\,\mathbf{xa} - 0.094\,\mathbf{xb}$, when 3.052 is the constant and 0.071 and -0.094 are the slope coefficients of **xa** and **xb** respectively. The slope coefficient of 0.071 as recorded by inter-molar width against masseter thickness in the relaxed state is lesser than previous value of 0.249 recorded in the simple regression analysis. This is owing to contribution from multiple variables in the multiple regression analysis[66]. Muscle thickness decreases as the mandibular plane angle increases due to the negative slope. The input from mandibular plane angle accounts more for the variation in muscle thickness than inter-molar width as made out from their slope coefficients. Together they account for more than 42% variability in masseter thickness in the relaxed state ($\mathbf{R^2}$ = 0.425). We see only two variables on the right side of the equation in the stepwise multiple regression analysis performed for relaxed and contracted masseter thicknesses, for the reason that others were not statistically significant (Tables-V&VI).

Table - I

VALUES AND DESCRIPTIVE STATISTICS OF VARIOUS VARIABLES USED IN THE STUDY

Sl.No	VARIABLE	MEAN	MEDIAN	MODE	RANGE	S .D
1.	Masseter Relaxed (mm)	8.58	8.50	8.50	4.8	0.95
2.	Masseter Contracted (mm)	11.24	11.0	11.8	4.9	1.17
3.	Cranial Breadth (mm)	135.4	135.0	130.0	68.0	12.89
4.	Cranial Length (mm)	179.4	180.0	180.0	22.0	5.63
5.	Facial Height (mm)	109.2	110.0	100.0	20.0	6.13
6.	Bizygomatic Width (mm)	130.0	130.0	130.0	28.0	7.04
7.	Intergonial Width (mm)	114.2	115.0	110.0	27.0	7.54
8.	Cranial Index	75.4	75.5	64.0	40.1	7.52
9.	Facial Index	84.2	83.5	80.7	24.3	6.46
10.	Gonial Index	87.9	87.5	84.6	15.0	3.52
11.	Intermolar Width (mm)	36.5	36.5	35.0	6.0	1.68
12.	Ramus Height (mm)	59.4	59.0	58.0	17.0	4.22
13.	Corpus length (mm)	74.6	74.0	78.0	15.0	4.30
14.	Cranial base Length (mm)	72.3	72.0	72.0	9.0	2.21
15.	Gonial Angle (deg)	120.3	120.0	116.0	18.0	4.46
16.	Mandi. Plane Angle (deg)	27.8	27.0	27.0	14.0	3.41
17.	Ramus Inclination (deg)	86.6	87.0	87.0	13.0	3.68
18.	TAFH (mm)	116.6	116.0	113.0	28.0	6.85
19.	LAFH (mm)	63.9	64.0	64.0	23.0	5.00
20.	TPFH (mm)	80.5	80.0	80.0	21.0	5.29
21.	LPFH (mm)	37.6	38.0	38.0	17.0	4.52
22.	LAFH/TAFH	54.7	54.2	53.7	6.8	2.00
23.	LPFH/TPFH	46.5	47.2	44.7	16.1	4.47
24.	Body Weight (Kg)	51.4	50.0	48.0	29.0	7.14

<u>Table - II</u>

CORRELATION WITH RELAXED AND CONTRACTED MASSETER

Sl No	INDEPENDENT VARIABLE	Masseter Relaxed (r)	Masseter Contracted(r)
1.	Cranial Breadth	0.154	0.009
2.	Cranial Length	0.257	0.215
3.	Facial Height	0.257	0.173
4.	Bizygomatic Width	0.383	0.434*
5.	Intergonial Width	0.557**	0.438*
6.	Cranial Index	0.062	-0.068
7.	Facial Index	-0.082	-0.171
8.	Gonial Index	0.394	0.117
9.	Intermolar Width	0.440*	0.307
10.	Ramus Height	0.199	0.285
11.	Corpus length	0.075	0.068
12.	Cranial base Length	-0.063	0.077
13.	Gonial Angle	-0.361	-0.270
14.	Mandibular Plane Angle	-0.324	-0.362
15.	Ramus Inclination	-0.104	-0.258
16.	TAFH	0.078	0.129
17.	LAFH	0.016	0.124
18.	TPFH	0.353	0.396*
19	LPFH	0.287	0.301
20.	LAFH/TAFH	-0.087	-0.353
21.	LPFH/TPFH	0.146	0.132
22.	Body Weight	0.415*	0.372

** indicates p value ≤ 0.01 ; significant at 1% level
* indicates p value 0.01 to 0.05 ; significant at 5% level

<u>Table - III</u>

Sl No	INDEPENDENT VARIABLE	Masseter relaxed Slope coefficient (b)	Muscle contracted Slope coefficient (b)
1.	Cranial Breadth	0.011	0.000
2.	Cranial Length	0.043	0.044
3.	Facial Height	0.039	0.032
4.	Bizygomatic Width	0.057	0.072*
5.	Intergonial Width	0.070**	0.067*
6.	Cranial Index	0.007	-0.010
7.	Facial Index	-0.012	-0.030
8.	Gonial Index	0.106	0.039
9.	**Intermolar Width#**	0.249*	0.213
10.	Ramus Height	0.044	0.078
11.	Corpus length	0.016	0.018
12.	Cranial base Length	0.031	0.034
13.	Gonial Angle	-0.076	-0.070
14.	Mandibular Plane Angle	-0.090	-0.124
15.	Ramus Inclination	-0.027	-0.081
16.	TAFH	0.010	0.022
17.	LAFH	0.003	0.028
18.	TPFH	0.063	0.087*
19	LPFH	0.060	0.077
20.	LAFH/TAFH	-0.041	0.020
21.	LPFH/TPFH	0.031	0.034
22.	Body Weight	0.055*	0.060

SIMPLE REGRESSION ANALYSIS WITH MASSETER THICKNESS AS DEPENDENT VARIABLE

** indicates p value ≤ 0.01 ; significant at 1% level
* indicates p value 0.01 to 0.05 ; significant at 5% level
# *next table*

Table – IV

SIMPLE REGRESSION ANALYSIS WITH MASSETER THICKNESS AS DEPENDENT VARIABLE AND INTERMOLAR WIDTH AS INDEPENDENT VARIABLE

Sl. No	Independent Variable	Slope (b) Coefficient	Standard Error	Significance
1	Intermolar Width	0.249	0.106	0.028
	CONSTANT	-0.536	3.878	0.891

R-Square = 0.193 Adjusted R-Square = 0.158

Masseter muscle thickness in the relaxed state **'y'** is dependent upon the intermolar width **'x'** and constant **'a'** according to the following equation :

y = a + bx

y = -0.536 + 0.249 x

Table -V

STEPWISE MULTIPLE REGRESSION ANALYSIS WITH MASSETER RELAXED AS THE DEPENDENT VARIABLE

Sl.No	Independent variable	Coefficient (b)	Standard error	Significance
1.	Intermolar Width	0.071	0.020	0.002
2.	Mand.Plane Angle	-0.094	0.044	0.047
	CONSTANT	3.052	2.617	0.256

R-Square = 0.425 Adjusted R square = 0.373

Relaxed masseter muscle thickness **'y'** is related to intermolar width '**xa'** and mandibular plane angle **'xb'** and constant **'xo'** by the equation

y = xo + b1 xa + b2 xb

y = 3.052 + 0.071 xa − 0.094 xb

Table -VI

STEPWISE MULTIPLE REGRESSION ANALYSIS WITH MASSETER CONTRACTED AS THE DEPENDENT VARIABLE

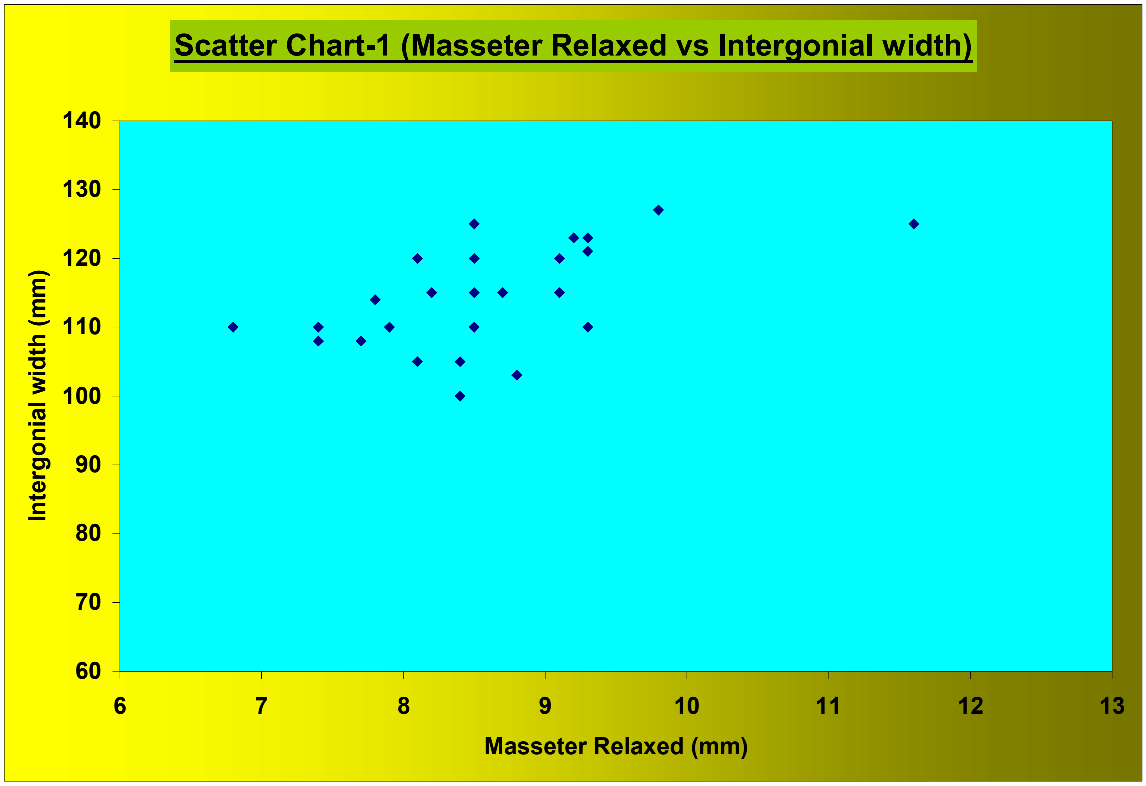
Sl.No	**Independent variable**	**Coefficient (b)**	**Standard error**	**Significance**
1.	Intermolar Width	0.069	0.026	0.017
2.	Mand.Plane Angle	-0.128	0.059	0.042
	CONSTANT	6.872	3.463	0.059

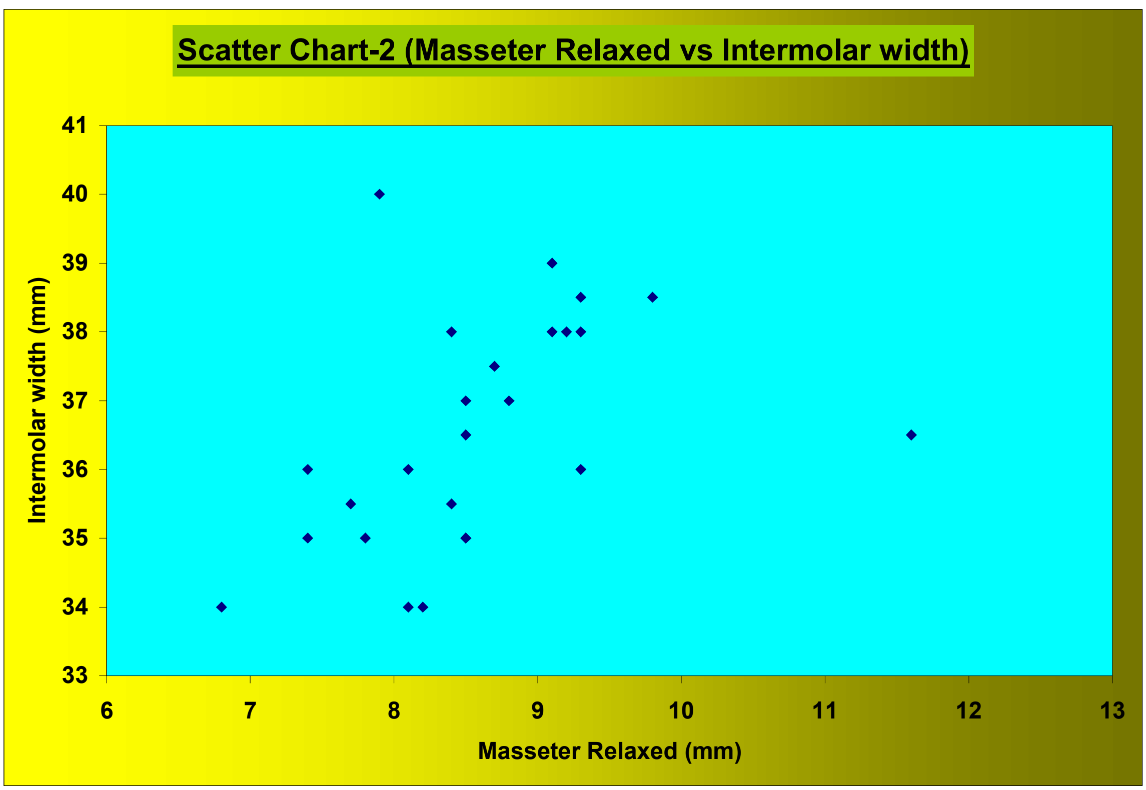
R Square = 0.332 Adjusted R Square = 0.272

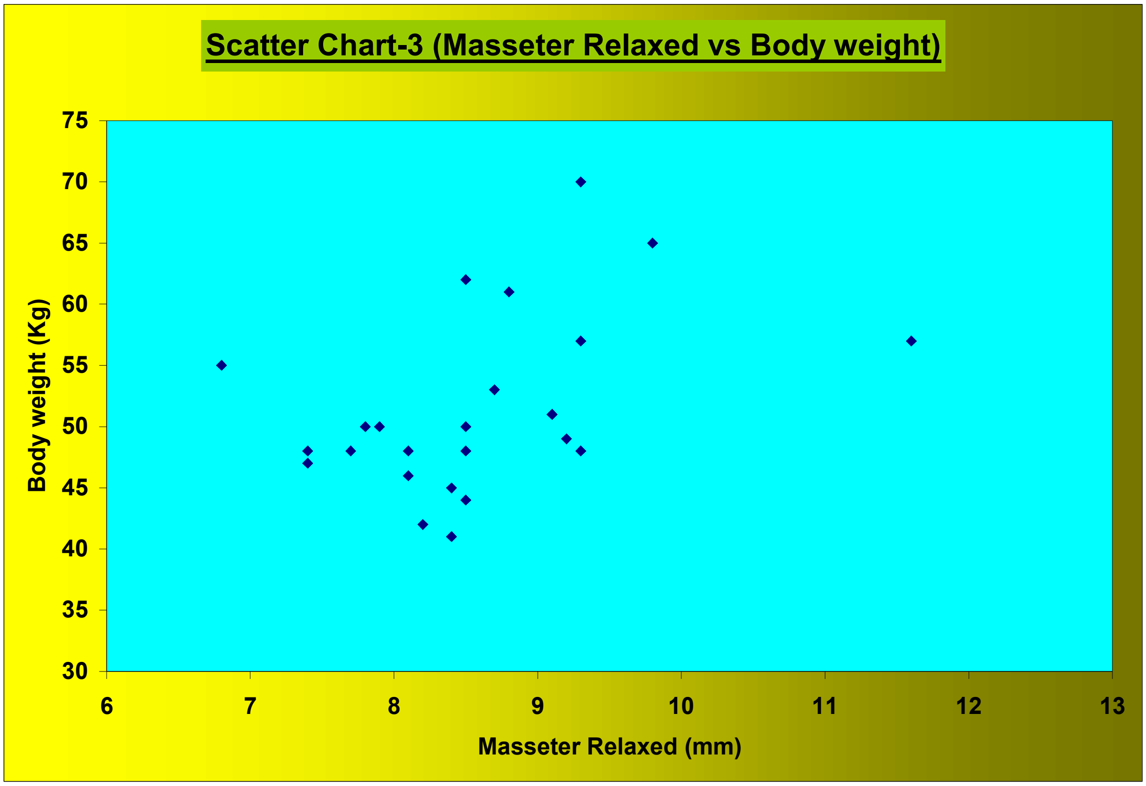
Contracted masseter muscle thickness **'y'** is related to intermolar width '**xa'** and mandibular plane angle **'xb'** and constant **'xo'** by the equation

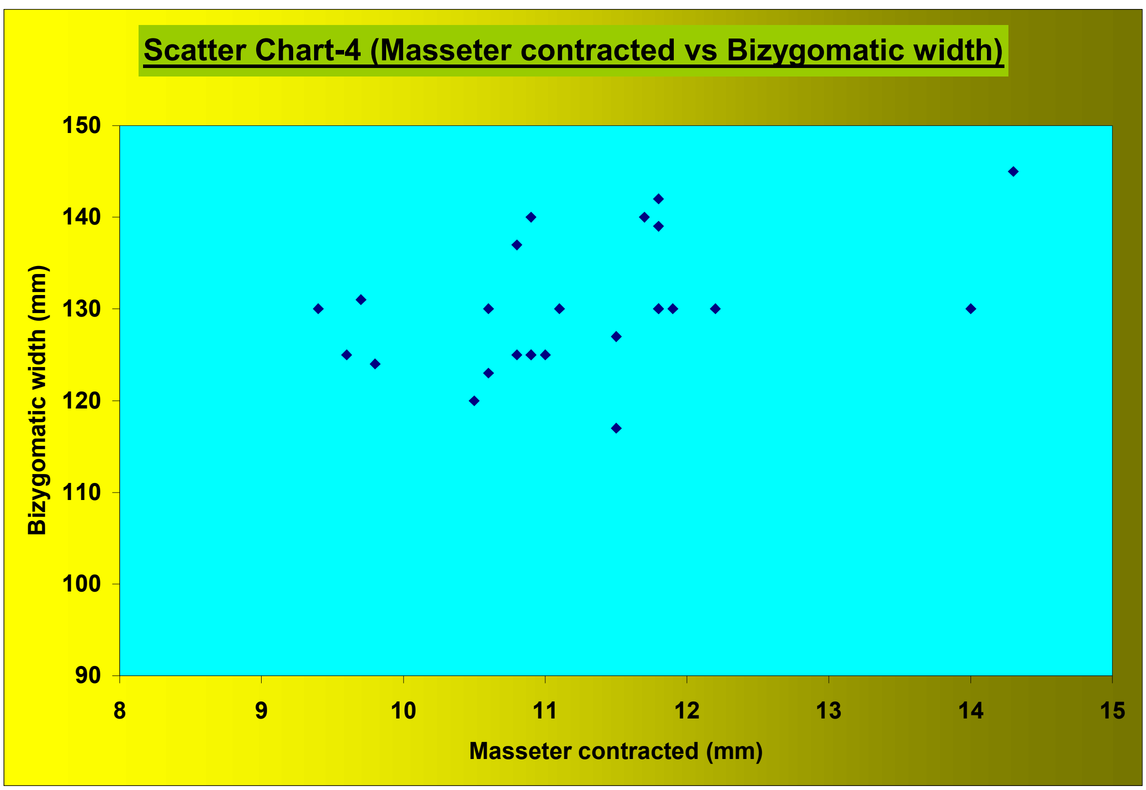
y = xo + b1 xa + b2 xb

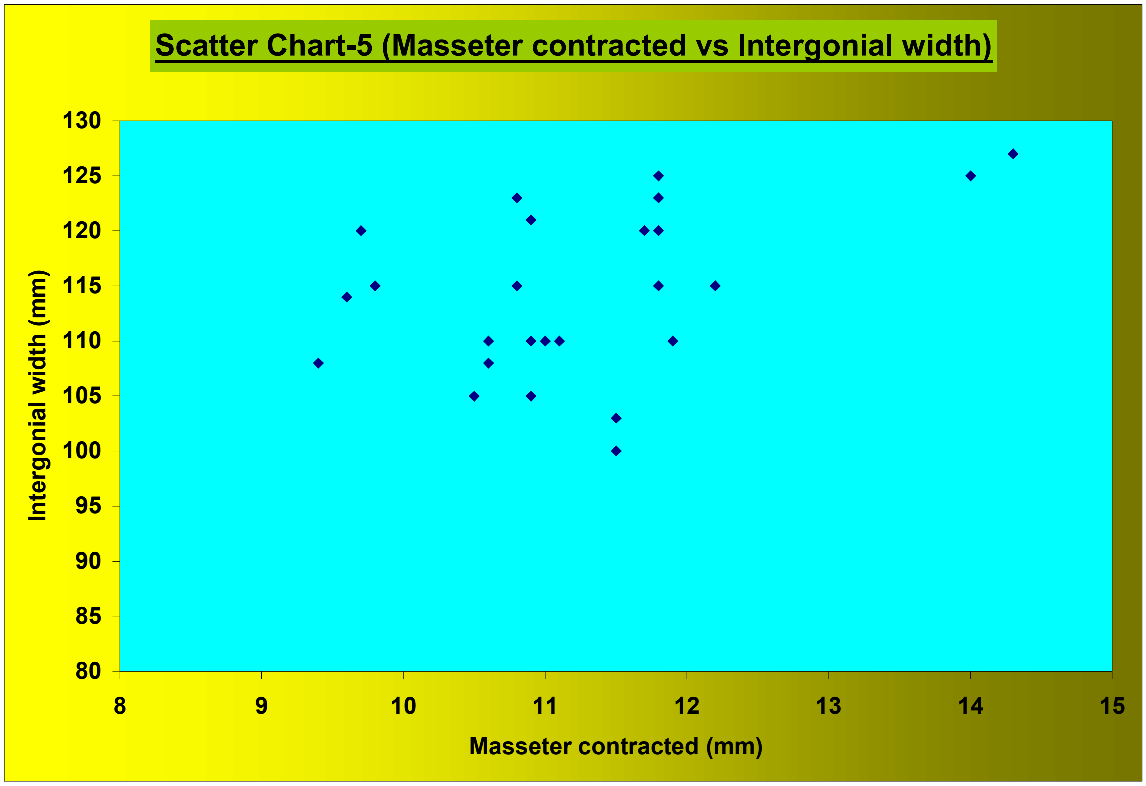
y = 6.872 + 0.069 xa – 0.128 xb

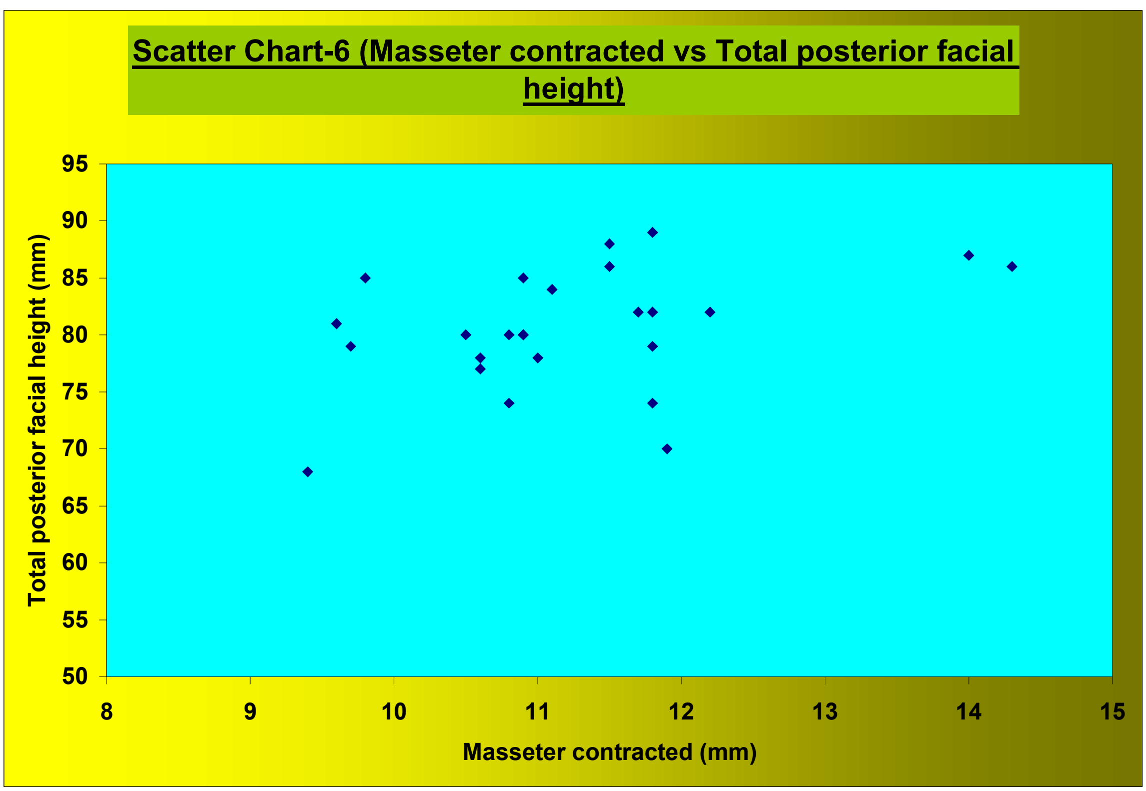

Scatter Chart-1 (Masseter Relaxed vs Intergonial width)
140
130
120
110
100
90
80
70
60
Intergonial width (mm)
6
7
8
9
10
11
12
13
Masseter Relaxed (mm)


Scatter Chart-2 (Masseter Relaxed vs Intermolar width)
41
40
39
38
37
36
35
34
33
Intermolar width (mm)
6
7
8
9
10
11
12
13
Masseter Relaxed (mm)


Scatter Chart-3 (Masseter Relaxed vs Body weight)
Body weight (Kg)
75
70
65
60
55
50
45
40
35
30
6
7
8
9
10
11
12
13
Masseter Relaxed (mm)


Scatter Chart-4 (Masseter contracted vs Bizygomatic width)
Bizygomatic width (mm)
150
140
130
120
110
100
90
8
9
10
11
12
13
14
15
Masseter contracted (mm)


Scatter Chart-5 (Masseter contracted vs Intergonial width)
Intergonial width (mm)
130
125
120
115
110
105
100
95
90
85
80
8
9
10
11
12
13
14
15
Masseter contracted (mm)


Scatter Chart-6 (Masseter contracted vs Total posterior facial height)
Total posterior facial height (mm)
95
90
85
80
75
70
65
60
55
50
8
9
10
11
12
13
14
15
Masseter contracted (mm)

DISCUSSION

Embryologically the bones that make up the maxillofacial region are membranous bones and as such are more susceptible to the environmental factors such as stimulating influence of muscles and extra-functional force in comparison with the long bones of extremities which are formed by cartilaginous ossification[16]. Head and neck consists of a number of independent, yet integrated functions; smell, taste, olfaction, speech, digestion, respiration, audition, vision and neural integration. Each function is carried out by a functional cranial component. Each functional cranial component consists of two parts.

1. All the soft tissues necessary to carry out the function called the *functional matrix*.
2. All the skeletal tissues which support and protect the functional matrix called the *skeletal unit*.

The functional matrix is primary to the facial growth and the presence, size, shape, spatial position and growth of any skeletal unit is secondary, compensatory and mechanically obligatory to changes in size, shape, spatial position of its related functional matrix[59].

Skeletal growth to a considerable extent is influenced by muscular growth, particularly, the parts of bones to which muscles attach develop in conjunction with the muscle[75]. Since both the coronoid process and the gonial angle area of the mandible are classical examples of bony muscular processes, these areas are strongly influenced by growth of the elevator muscles of the mandible. The mandibular ramus does not grow by lengthening of the ramus from apposition of bone at the gonial angle, which might be expected if lengthening of the muscle directly produced new bone in that area. Instead, the gonial angle area is often resorptive, while mandibular length is produced through proliferation at the condyle and along the posterior border of the ramus in areas away from the muscle attachment. The mandible appears to respond as if growth of the muscles and surrounding soft tissues translated it downward and forward, allowing upward and backward proliferation at the condyle. The mandibular ramus has to remodel as it relocates postero-superiorly. As the brain and cranium widen and expand the zygomatic arches relocate inferiorly and laterally with enlargement. The muscles attached to the zygomatic arches are also responsible for this effect[19].

Individuals with an excessively large anterior face height often exhibit other cephalometric characteristics like small posterior face height, steep mandibular plane angle, large gonial angle etc. These characteristics have been described as the long-face syndrome[88] and as skeletal open-bite[86].

Subjects with a high bite force have a relatively short lower anterior facial height[41]. **Varrela** demonstrated this difference of morphology comparing skulls from 17 and 18 century on hard diet to living individuals and proposed that growth of craniofacial skeleton is controlled by masticatory stress[108]. For long-face subjects, significantly smaller maximum molar bite forces have been found compared to in normal individuals[75,76,101].

Bite force magnitude is related to jaw muscle thickness[85,99],facial morphology[34,35,41,75,76], fiber type composition[80], sarcomere length[105], jaw muscle activation level[106], direction of bite[47,107], age[76], sex[41] and occlusal contact measures[4,51,52] .Other factors which seem to influence the bite force are the state of dentition, location within dental arch where force is measured, psychologic and mental conditions during the effort, attitude of the investigator and the subject, malocclusions, presence of tenderness in the muscle[14] and the extent of vertical separation of the teeth due to the bite fork[41]. All these factors explain the broad range of variability of the results obtained in different bite force studies. **Hannam and Wood** suggested that similar bite force efficiencies can be found in subjects with disparate facial features[25].

Masseter muscle thickness is found to be the most significant factor controlling bite force[4,79,101]. Correlations of 0.80 between maximum molar bite force and masseter and medial pterygoid muscle cross-sections have been published[85,99]. This is in agreement to the work of **Schantz *et al*** who found that muscle cross section is proportional to the maximal isometric strength of the muscle[87].

Differences in facial morphology result in significant differences in the spatial orientation of the muscles which in turn determine the moment arm of the masticatory muscles[95]. The dento-skeletal morphology have been shown to be related to masticatory muscle orientation in children[39].**Van Eijden** demonstrated a variation in direction of bite force between long face and normal adults[107]. Subsequent research showed that the variation of the spatial orientation of the jaw muscles is small and does not significantly contribute to the explanation of the different molar bite-force levels of long face and normal subjects[102,103].

Surface Electromyography (EMG) detects the firing of motor units which can be used to monitor muscle activity. EMG measurements have been taken at postural rest, chewing, swallowing and maximal bite. Electromyographic studies, showed decreased activity in all jaw muscles in long-faced persons[1,32,33,64]. Masseter and digastric activities shown to have significant negative correlation with vertical craniofacial morphology[97,98]. Mouth breathing is found to be associated with reduced EMG activity of masseter[71]. High correlation between bite force and

EMG activity of masseter is also observed[50].

Many studies reported to date on facial morphology and EMG suffers from methodological limitations. Some, for example, use only a single measure of biting force, typically a maximum bite force[75,76], and these are compromised by unknown levels of subject motivation and short-term fatigue and pain. Others measure EMG activity during activities such as chewing, clenching, or swallowing that may differ considerably among subjects[2,53,54,64]. Furthermore, few have controlled for age or gender[5,62,75,94]. Long time EMG activity registration is used in some studies. Most of the strong bursts of the masseter muscle appeared only during meals and a number of low amplitude bursts were observed during the entire day[63].

Craniofacial morphology is determined by the strength of the jaw muscles or vice versa has been an area of research. Vertically oriented craniofacial growth has been described as a result of progressive atrophy of the jaw muscles[23,48]. Masseter is affected by muscular dystrophy and to it is attributed the etiology of associated long face pattern[43,65,74]. **van Spronsen *et al*** found that masseter muscle in long face is thinner by 30%[101]. Decreased jaw muscle activity has been demonstrated in long face subjects. Animal studies have supported EMG studies[83,114]. **Hunt *et al*** showed that the changes in the masseter fiber type seen in long face are due to primary myopathy than a reflection of functional requirements[30].

These reports hold up the theory that the jaw muscles influence craniofacial growth. Based on these findings **Ingervall *et al*** proposed training of the jaw muscles of long-face children by having them chew daily on tough material to strengthen the muscles and to induce a more favorable anterior mandibular growth rotation[35]. All this goes against the philosophy that the long-face pattern elevator muscles fail to gain strength in the mandible[75,76,117]. It is the muscle that controls morphology not *vice versa*.

The bone apposition rate in the mid-palatal suture has been shown to be lesser in rats with decreased functional demands, whereas their maxillary arch was narrower[38,114]. Also the greater arch width found in medieval dentitions compared with those from a modern control sample is considered to be due mainly to differences in diet and masticatory function[26]. **Kasteros** has shown that broader maxillary arch is associated with thicker masticatory muscles in rats[37]. Also significant correlations have been found between transverse skull dimensions and maximal temporalis and masseter cross sections in rats[100].

Besides sutural growth, differences in the transverse width of the alveolar process or in the buccopalatal inclination of the posterior teeth might also contribute to differences in maxillary dental arch width**. Masumoto *et al*** reported that the lower molars of skulls with a long facial configuration were more lingually inclined than in skulls with an average or short facial configuration[56].

Maxillary inter-molar width is shown to decrease slightly after puberty in females[7,8,55]. A direct, significant association with masseter thickness both during contraction and relaxation is reported for the inter-molar width in the same sex[45]. Statistically significant correlations were seen between thickness of masseter muscle in the relaxed state and inter-molar width in the present study. Significant correlations also have been reported between masseter cross sectional area and bizygomatic width and intergonial width[25,78]. Moderate association was seen between intergonial width and masseter thickness in relaxed state (**r** = 0.557) and weak association between intergonial width and masseter thickness in relaxed state in this study (**r** = 0.438) and the findings were statistically significant (Table-II). Growth in the transverse dimension for female facial skeleton has been shown to be completed by 17 years[90].

Relationships exist to a limited extent between craniofacial morphology and the cross-sectional areas of the jaw muscles in adult males[101]. Highly significant correlations have been reported in females between masseter muscle thickness and facial morphology variables[40,84]. The maxillary arch width demonstrated positive association with masseter muscle thickness in a recent study in female sample[45].

It has been shown that Type I fibers with slow shortening velocities produce less force per unit area than do the Type II fibers with rapid shortening velocities[11,12,13]. Hence, muscles with a high percentage of Type I fibers are less powerful than muscles with predominantly Type II fibers. **Ringqvist** found a significant positive correlation between molar bite-force and the proportion of Type II masseter fibers[81,82]. Unfortunately, no consensus exists about the distribution and size of muscle fiber types in the jaw muscles of long-face subjects[10,21,89,115]. Association between type of fibers in a given area of muscle cross section and the maximal tension developed by that unit was shown to be poor by **Schantz**[87]. The intrinsic morphology of the muscle was assumed to have minimal significance in this study.

Masseter muscle is an efficient producer of vertically oriented bite force[25].Significant relation between bite force magnitude and cross-sectional area of the masseter have been reported in the literature[79,99]. **Van Spronsen *et al*** showed that the MRI cross-sectional area of the masseter muscle exhibited the most marked differences among the masticatory muscles between long-face and normal individuals[101].

The growth and activity of the masticatory muscles could be studied only by indirect methods in the past, such as recording of bite force, or by examination of muscle biopsies and autopsies in cross-sectional studies. Computer Tomography (CT)[24,109,110,11,112] and Magnetic Resonance Imaging (MRI)[85,99,100] have been used for imaging of the human jaw muscles. CT, however, is disadvantageous because of radiation effects, and MRI requires relatively long exposure times. Compared with CT and MRI, Ultrasonography is advantageous because it has no known deleterious biological effects, it is rapid and inexpensive, and the equipment can be handled easily. However, Ultrasonography allows for registration of only superficial muscles. Another restriction in the use of Ultrasonography is that it is not always possible to cover the whole cross-sectional muscle area by the transducer. Therefore investigators have measured the masseter muscle thickness[4,40,78,84]. **Close *et al*** compared the ultrasound thickness and the cross-sectional area of masseter and found high correlations between them[14]. Positive correlation between masseter volume and masseter thickness is reported[57].

Ultrasonography was found to be a reliable and accurate method for study of the thickness of the masseter muscle by **Kiliaridis and Kalebo**[40]. Ultrasound scanning gives an uncomplicated and a reproducible access to parameters of jaw muscle function and its interaction with the cranio-mandibular system. It produces a well-defined depiction of the muscle with distinct tendinous structures[4]. Similar view is shared by **Raadsheer *et al*** who compared Ultrasonography to MRI for *in vivo* masseter thickness registration[77].

Masseter muscle is thicker in the anterior aspect of muscle belly. Previous investigators have measured the point of estimated maximum masseter thickness[40,45,77,84]. **Kubota *et al*** recorded mean of several measurements along the width of muscle belly[67].Others have recorded the mid point of masseter belly and their readings were smaller. The measurement site in this study was similar to **Kiliaridis and Kalebo's** ; the thickest part of the masseter close to the level of the occlusal plane, halfway between the zygomatic arch and gonial angle, approximately at the centre of the medio-lateral distance of the ramus[40]. The dimension for masseter thickness (Mean ± S.D) for females in the relaxed state was 8.6 ± 0.95 mm and contracted state was 11.2 ± 1.17 mm in the present study (Table–I). This compares well with the findings of **Kiliaridis and Kalebo** who found the thickness of 8.7 ± 1.6 mm for relaxed masseter and 13.0 ± 1.8 mm for contracted masseter[40].

An attempt was made to measure masseter thickness in both relaxed and contracted state in this study because the transducer was accused of compressing the relaxed muscles and resulting in erroneously small muscle measurements[40,77]. No attempt was made to compare the muscle thickness during contraction and relaxation. The mean thickness of the right and left sides were taken as the reading since females are expected to have some degree of asymmetry in muscle morphology[14].

The thickness of the masseter muscle during relaxation was found to be significantly related to the women's body weight, being thicker in the subjects who had large body weight (Table-II). **Kiliaridis and Kalebo** had found a similar association with contracted masseter. However, no attempt was made to compare muscle thickness with the stature or body composition.

Cranial, facial and gonial indices are estimated through standard anthropological procedures in this study. Anthropologic measurements were found to be more reliable in estimating facial width than standardized facial photographs[40]. Transverse skull measurements were not taken from PA cephalograms. Even for analysis of vertical components, although easily viewed from sagittal cephalometric radiographs, cannot be fully understood without the assistance of a PA cephalometric radiograph as bilateral vertical asymmetries can only be evaluated from a frontal view[90]. This was done keeping the radiation hygiene in mind as pointed out by **Raadsheer *et al***[79]. Other reasons why PA cephalometric films have not been used as extensively as the lateral cephalometric films in growth studies is, the distortion that may be created by the slight movement of the head in the transverse plane, as well as the vertical plane. Also the radiographs have to be taken in a very rigid cephalostat and the same operator has to take the films over the length of the study.

The relationship between masseter muscle thickness and anterior face height was found to be negative[4,6,40,78,101]. Also significant positive correlation was established with total posterior facial height and ramus height. A significant correlation with total posterior facial height is demonstrated in the present study for contracted masseter thickness (Table–II). **Weijs and Hillen** reported that the muscle cross sectional area was negatively correlated with anterior facial height and gonial angle and positively correlated with head width and mandibular length[110,112]. Also the muscle cross sectional area as well as thickness has been found to negatively correlate with mandibular plane angle[4,24]. Such a negative relationship is demonstrated in the present study (Table-V & Table-VI).

The associations between masseter muscle thickness and facial morphology variables were moderate to weak, as made out from their correlation coefficients[66] (Table-II). These are lesser than the values given by **Kiliaridis and Kalebo** (**r**= 0.4-0.7)[40]. Weak correlations were demonstrable in previous studies done in male[67] sample and female sample[4].

SUMMARY AND CONCLUSION

The present investigation was carried out to study the relationship between the ultrasonographic thickness of the masseter muscle and the facial morphology variables including the width of the maxillary dental arch. The sample comprised 25 female dental students with Class I molar relationship. The thickness of the masseter muscle was measured Ultrasonographically. Recordings were performed bilaterally with the muscles both in relaxation and under contraction and the mean values were recorded. Anthropological measurements were obtained with an anthropological caliper. Lateral cephalograms were hand traced and linear and angular dimensions calculated. Maxillary inter-molar width was measured as the distance between the palatal surfaces of the first permanent molars.

Pearson’s correlation coefficients were obtained to show the association of facial morphology variables to masseter thickness. Positive correlations were obtained between masseter muscle thickness in the relaxed state and inter-molar width, intergonial width and body weight. Bizygomatic width, intergonial width and total posterior facial height showed positive correlations with masseter thickness in the contracted state. Even though, other facial morphology variables also registered weak correlations, they were not statistically significant. The most probable reason for this could be the small sample size. Multiple regression analysis revealed positive relationship between masseter thickness and inter-molar width and negative relationship between masseter thickness and mandibular plane angle. The findings of this study indicate that the functional capacity of the masticatory muscles may be considered as a factor influencing the facial morphology including inter-molar width.

Appraising the growth pattern of the face is an important aspect of orthodontic diagnosis. The maxillary arch width influences the mandibular arch width. Maxillary expansion is found to be more feasible in brachycephalics compared to dolicocephalics. The findings of this study reiterate the significance of oro-facial muscles in growth and there by in orthodontic practice.

The following **conclusions** were drawn from the study.

1. The dimension for masseter muscle thickness (Mean ± S.D) for females in the relaxed state was 8.6 ± 0.95 mm and contracted state was 11.2 ± 1.17 mm.

2. Masseter muscle thickness was found to be related to variables of facial morphology like bizygomatic width, intergonial width, inter-molar width, total posterior facial height and body weight.

3. The better understanding of the complex interaction between masseter muscle function and dento-facial growth can be obtained in the future studies with larger sample size.

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